Review of Load Frequency Control Topologies and Control Techniques

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ABSTRACT

When it comes to human-made systems, power grids are unparalleled in complexity. These systems can't function in a steady state unless there are a lot of control loops. Power systems rely on voltage frequency, which must be carefully controlled. Power systems use main and secondary frequency control loops to regulate voltage frequency. Keeping the frequency at a suitable level after an interruption is the job of secondary frequency control, also known as load frequency control (LFC). Additionally, LFC procedures govern the transfer of authority across several control zones. Over the past few decades, numerous control strategies for power systems' Load Frequency Control (LFC) have been proposed. This article provides a thorough review of the literature on LFC. In order to better understand current and future smart power systems, this article first sorts and analyses the most popular LFC models for various power system topologies. A number of control groups are created from the proposed LFC control methods once they have been evaluated. The report concludes by highlighting the topics of future study in LFC as well as the gaps in current knowledge.
Keyword: - Load Frequency Control, Distributed Energy Resources.

1. INTRODUCTION

We are cognisant of the fact that, as a result of variations in industrial and consumer loads, a power system's active and reactive power requirements are inherently variable. Because of this, the input supply—whether it's steam for turbogenerators or water for hydro generators—must be carefully controlled; otherwise, machine speed changes could modify frequency, which would be extremely harmful to the power system's operation. Although it is possible in theory, it is not practicable to achieve zero frequency variation. Therefore, there is a maximum allowable fluctuation in frequency. The industry's expensive machinery is vulnerable to higher frequency variations, which could harm consumers. At this same moment, all of nature's systems are linked. When something goes wrong with the electrical system, it's usually because of multiple systems working together. Keeping to a regular schedule thus becomes quite difficult.

Automatic digital control presents its own set of problems, such as communication delays, and is therefore insufficient for a contemporary, highly linked system that requires regulation by hand. A more reliable and, most importantly, user-friendly controller is required to deal with the frequency variations. Over 90% of industries utilise PID controllers because they are simple, clearly functioning, and useful. However, there were control experts who argued that PID controllers calibrated using traditional methods were unreliable. As a result, cutting-edge control strategies were required, including sliding mode control, H-infinity, QFT, and LMI-based approaches. At first glance, these strategies seemed to outperform PID control systems; however, it has since been proven that PID controllers are complicated and have difficulty being robust when faced with uncertainty. Due to the limits of optimum control techniques and the widespread use of PID controllers, the researchers saw the need to merge the two. When dealing with non minimum phase behaviour, rejecting disturbances, and handling parametric uncertainties, this controller type performs better than others. Several control methods that rely on PID are summarised in this article. A primary goal of this research is to compile all of the current controller approaches to the LFC problem.

2 MOTIVATION

Disruptions to the electricity system have been more common in recent years, and this trend has been the subject of numerous studies. For instance, in 1999, Brazil experienced a blackout, in 2003, the Northeastern United States and Canada, and in 2005, Russia. It was actually in July of 2012. Nearly 620 million people, or about 9 percent of the world's population, lost electricity in India, making it the country with the worst power outage in recorded history. These problems can be avoided if the load frequency stays constant. Variations in frequency might have an immediate impact on how the electrical system functions. Damage to equipment, decreased load performance, disruption of several power system protection methods, and even system failure can result from large changes. Therefore, maintaining the system frequency within the allowed tolerance range is of utmost importance. Effective control strategies are crucial for addressing frequency variations, as they have the potential to enhance system performance and security. One of the most important and straightforward ways to deal with these issues is the PID controller. As a result, several PIDs and variations, such as two-degree-of-freedom PID controllers, must be investigated. Controller for proportional-integral-derivative (PID) systems. There are a number of parts, including a PID controller and an IMC system. Raising PID's profile as a resilient controller that can handle effects of communication latency, noise, disturbance rejection, and parametric uncertainty is crucial.

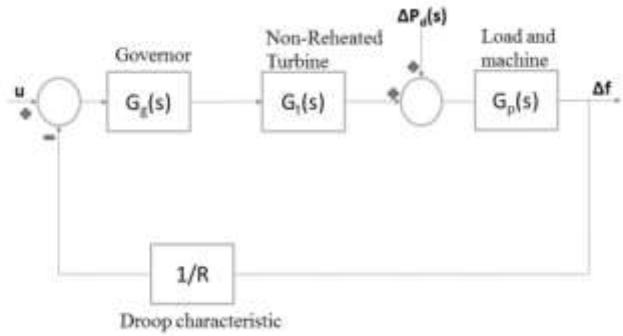

Fig. 1. Linear model of a single-area power system

3 LOAD FREQUENCY CONTROL TOPOLOGIES

The term "conventional power systems" refers to electric power systems in this section that use fossil fuels to produce electricity. Thermal, hydroelectric, and nuclear power plants are the most common types of power plants used by these systems. The size of a power system determines its classification: single-area, two-area, three-area, and four-area systems. Detailed assessments of the Load Frequency Control (LFC) power system models are provided in the following sections. There are a plethora of Load Frequency Control (LFC) frequency response models available online.

3.1. Single-Area Power Systems

The initial studies on frequency control mostly concerned load frequency controllers for power systems serving a specific area. The literature reviews many models of single-area power systems that use LFC control approaches [1,2]. single-area power systems that rely on thermal power plants are mentioned in [1-3]. Discussed in [4] is a mathematical model that is still in its early stages but describes the frequency response of power networks that serve a certain area. For power systems that use thermal, hydro, and gas as energy sources, [5] lays out single-area frequency response models. Electric power networks that incorporate hydropower units are described in detail in [6], where the authors present a comprehensive model for the frequency response. An independent generation control system that accounts for certain nonlinearities is provided by [5] for hydroelectric power plants. The interaction between reactive and active power regulation impacts LFC models of power systems that serve a given area, as demonstrated in [3].

3.2 Single-Area Power Systems

For two-area power systems, the architecture of LFC and AGC systems is described in [7]. Studies examine the effects of tie-line models on the load frequency regulation of two-area power networks. Displayed in [8] are the LFC models that account for the frequency response of the voltage control loop in two-area power systems. In order to account for the nonlinearities of the governor dead-band (GDB) and generation rate constraints (GRC), the authors of [9] propose frequency response models for two-area power systems. As mentioned in [10], the frequency response model is made simpler by lowering complexity. Particularly discussed in this work are nonlinear multi-source two-area LFC models [11]. Reference [10] discusses two-area power systems and LFC models that include parametric and nonparametric uncertainty. In reference [12], a method for Load Frequency Control (LFC) is provided for two linked power systems that use HVDC transmission lines. In [12], frequency response models are introduced for a two-area power system that uses reheat-thermal turbines connected by AC/DC cables. In thermo-thermal two-area power systems, methods for managing the frequency of loads are proposed in [8,13] that consider communication channel delay. This two-area power system's frequency model for reheat thermal turbines with dead-band zones for governors is detailed in [8]. Reheat thermal turbine power systems account for GRC non-linearity, as stated in [14]. For hydro-hydro interconnected power systems, the LFC method is recommended in light of the non-linear characteristics of hydro power plants [15]. The article proposes models for two-area power systems that incorporate load frequency control (LFC) and superconducting magnetic energy storage (SMES). A frequency management model for two-area power networks is described in [17] by integrating the impacts of SMES and batteries. A standard two-area power network is used to simulate electric vehicles and energy storage systems in reference [18]. In [19], the stochastic aspects of electricity demand are discussed. In [20], the LFC model takes into account renewable energy source uncertainty.governor systems in two-area.

3.3 Three-Area Power Systems

References [21,22] include studies on LFC modelling for interconnected three-area power systems. In the LFC model's tri-regional interconnected power system (shown in [50]), steam-hydro power plants are used in the first two zones, while steam power plants are used exclusively in the third zone. This study examines three domains of control for thermal power systems in accordance with the methodology presented in [23]. The control zones and radial and ring-wise connections of three-area integrated power systems are the focus of the study in [24]. In [25], an LFC model is presented for a three-area power system that incorporates GDB and GRC nonlinearities. Investigating the impact of communication channel latency on LFC in linked three-area power systems is done in [26]. Reference [27] emphasises the impact of parametric uncertainty on the load frequency regulation of three-area linked power systems. The authors of [28] present a frequency response model for three-area thermal power systems. The LFC is designed for three-region hydropower systems in [25]. It is possible to build up a three-area hydrothermal power system by using load frequency controllers [21]. In [29], the LFC is laid out for power systems that use multiple sources of energy, like as thermal, gas, and hydro.

3.4 Four-Area Power Systems

In order to maintain an appropriate frequency range, extensive power systems are sometimes divided into many control zones. The challenges of LFC are detailed in [30] in four interconnected power networks. In a pioneering effort in the field, Malik et al. [31] offer a Load Frequency Control (LFC) for interconnected hydropower systems covering four categories. In [32], we can see frequency response models that function with load frequency control for interconnected power networks that span four areas. In [33], the topic of improving linear feedback control models for linked power networks by incorporating nonlinearities such as generator droop behaviour and governor response characteristics is covered. The inherent uncertainties of the power system parameters are included while utilising fuzzy control in an LFC model, as stated in [34]. A four-area linked power system is described in [35]. It includes a variety of energy sources and turbines, including hydropower, gas, non-reheat thermal, and reheat thermal power plants. For the purpose of connecting four thermal power regions—each of which has three thermal units and one hydro unit—a variety of topologies, including rings and longitudinal configurations, are proposed in reference [37]. Reheat thermal units connected to a secondary hydro control area via a tie-line form a three-area system depicted in [38] as the Load Frequency Control (LFC).

4. SOFT COMPUTING BASED PID CONTROL TECHNIQUES

Many complex heuristic search algorithms, primarily drawn from mathematics, biology, chemistry, and physics, are part of the Computational Intelligence (CI) family that uses soft computing techniques. Bo Xing (2014) provides a comprehensive list of 134 approaches. The Big Bang Big Crunch (BBBC), Firefly (FFA), Base Optimisation Approach (BOA), and Genetic Algorithm (GA) are just a few renowned and widely-used algorithms. They sidestep the issues plaguing traditional optimisation techniques by incorporating randomisation, welcoming uncertainty, and making use of inductive reasoning. Researchers have been employing them to calibrate PID parameters in LFC situations because to all the benefits they offer. To optimise the parameters of a fractional order PID controller—more flexible than a conventional PID controller—and Yesil (2014) to modify the scaling factor and footprint of uncertainty (FOU) for the membership functions of an interval type-2 fuzzy PID controller, the BBBC algorithm was utilised. Similarly, Kumar et al. (2017) utilised it to optimise the parameters of a conventional PID controller. While Jagatheesan et al. (2017) optimised the PID controller settings using FFA and compared the results with GA and PSO, Dhillon et al. (2015) tuned a PID controller for a five-area LFC model efficiently by combining fuzzy-based inferences with the PSO approach. Ahuja et al. (2014) introduce a robust FOPID controller for a single area non-reheated power system using the PSO algorithm. The advantages of gaseous substances and fractional order were brought together by Zamani et al. (2016). In consideration of the governor's saturation limits, a FOPID controller is developed using Brownian Motion Optimisation (GBMO). Sahu et al. (2013) used differential evolution (DE) to create a 2-degree-of-freedom PID controller for a realistic power system, which accounts for physical constraints such as time delay and generation rate limitations. A revised target function was employed by the writers after factors including peak overshoots, frequency settling periods, weighted integral time absolute error (ITAE), and the damping ratio of dominating eigenvalues were taken into account. Results from an analysis of a coupled two-area thermal system using Craziness-based PSO (CPSO) show that the suggested method works. The paper by Debbarma et al. (2015) introduces a two-DOF proportional integral double derivative (PIDD) controller for a three-DOF thermal system, and it demonstrates robustness despite minor shifts in the SLP's location. To begin with, Guha et al. (2016) utilise it to assess QOGWO, an optimisation algorithm, in comparison to other intelligence methods such as ANN, adaptive neuro-fuzzy inference systems (ANFIS), and fuzzy logic. Then, they use it to an LFC problem. Researching resilience in an unfamiliar context is best accomplished through the use of a sensitivity analysis. Abdelaziz and Ali (2015), Yesil et al. (2014), El-Hameed and El-Fergany (2016), and Abdelaziz and Ali (2015) all offer more details on how to handle the LFC problem using soft computing methods.

Because of its many advantages, control system design based on evolutionary computing has attracted a lot of attention from academics in the past decade. Usability, cheap solution prices, and solution guarantee are three of the most well-known advantages of employing soft computing technology. They can deal with complex, nonlinear, and unexpected technology issues. In contrast to other technologies, control systems that employ soft computing methodologies have been demonstrated to be practical in various studies. Using soft computing technologies to optimise the settings of load frequency controllers led to greater control and dynamic system performance. The controller gains have been fine-tuned using a number of evolutionary optimisation strategies. Initial studies on the topic showed that genetic algorithms (GAs) might effectively address power system issues, including load frequency control (LFC) [39]. Hydrothermal power facilities may now control their generation autonomously thanks to a genetic algorithm [40]. In a similar vein, power systems employ GA to optimise the gains and parameters of LFC fuzzy controllers. Particle swarm optimisation (PSO) is a popular method for addressing the LFC issue in distributed power grids. It mimics the cooperative behaviour observed in swarms of fish and birds. Population dynamics are the basis of PSO. Using Particle Swarm Optimisation (PSO), the Load Frequency Control (LFC) problem in single-area power systems is addressed in [41]. Notably, PSO has similarly tackled the LFC issue in distributed power systems that use thermal, hydro, and gas turbines, among others (as stated in [42]). Using additional soft computing approaches, the authors of [43] propose hybrid PSO algorithms to enhance LFC. Several proposed soft computing methods have emerged as potential answers to the age-old issue of load frequency management in power systems both new and old. For instance, algorithms like differential evolution (DE) [44], firefly algorithm (FA) [45], artificial bee colony (ABC) [47], grey wolf optimiser algorithm (GWO) [48], and wind-driven optimisation algorithm (WOO) [49] are used to optimise LFC in interconnected power systems.

5. OPTIMIZING LFC PROBLEM

Load frequency controllers have two primary roles to play in an interconnected power system that experiences a disruption: (i) bringing the steady-state frequency back to its nominal value and (ii) keeping the transmitted power at certain levels. Accurate calibration of load frequency controllers is essential for accomplishing these goals. Several objective functions can be used to express the optimisation problem of LFC in connected power systems. Reducing frequency and tie-line power flow irregularities is the main goal of LFC, which will improve the power system's operation, control, and stability [49]. One common metric used to reduce variance is area control error (ACEi):

$$ACE_i = \Delta P_i + \beta_i \Delta f_i \quad (1)$$

Where, $\beta_i = D_i + \frac{1}{R_i}$

In this context, fi stands for the frequency deviation in p.u., Pi for the power flow deviation in p.u., i for the frequency bias, Ri for the governor droop, and Di for the power system damping. The proposed objective function for the LFC decision maker may incorporate several indications like as settling time, overshoot, and oscillation damping enhancement to help it achieve its objectives. The correct implementation of soft computing approaches with the right objective function is essential for achieving optimal LFC performance. The target functions have been updated to include frequency inaccuracy and tie-line power based on a number of criteria found in the literature. The integral of absolute error (IAE), integral of time multiplied by absolute error (ITAE), integral of squared error (ISE), and integral of time multiplied by squared error (ITSE) are the main metrics used to assess design aspects of load frequency controllers [50, 51, 52, and 53]. Following the given criteria, the following objective functions are frequently used in literature to optimise load frequency controllers [49]:

$$IAE = \int_0^{t_{sim}} |e(t)|dt \tag{2}$$

$$ISE = \int_0^{t_{sim}} e^2(t)dt \tag{3}$$

$$ITAE = \int_0^{t_{sim}} t|e(t)|dt \tag{4}$$

$$ITSE = \int_0^{t_{sim}} te^2(t)dt \tag{5}$$

Each tie-line's (ij) weight for transmitted power error and each region's (i) weight for frequency error are taken into account. When certain locationsand/or tie-lines are given more importance than others, the goal functions take this into account and assign appropriate weights to the frequency deviation and/or transmitted power deviation [49].

Rapid power balance can be achieved by minimising the settling periods of frequency error and tie-line error as well as damping oscillations of frequencies [50].

The settling time (ST) is defined as the moment at which the signal's final value stabilises below 0.00001 [50]. Words' relative weights in the objective function should represent their relative significance to the whole.

As controller tuning for LFC is a non-convex, non-linear and multi-variable optimization problem, it must be solved by a metaheuristic algorithm. The literature review explored that in the past decade, researchers have employed numerous metaheuristic algorithms. But most of them suffered from premature convergence and local stagnation. A promising solution to these problems is seeming from the application of Harris Hawk Optimization (HHO). The authors will attempt to incorporate HHO for tuning the LFC controllers.

6. CONCLUSION

This article takes a look at how electricity systems are currently using load frequency control. Given their significance, the mathematical models of frequency response for many types of power systems—both traditional and smart—are subjected to thorough evaluation. Distributed generation, microgrids, and smart grids are among the numerous smart system models that have been identified. Modern power grids that make extensive use of renewable energy sources are also mentioned. In addition, both traditional control techniques and adaptive control systems are thoroughly evaluated. We also take a look at some of the more up-to-date control approaches, including resilient control, optimum control theory, and control technologies based on soft computing. One example is load frequency regulation in power systems. Several research directions and gaps in the field of current load frequency control systems are shown at the end.

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